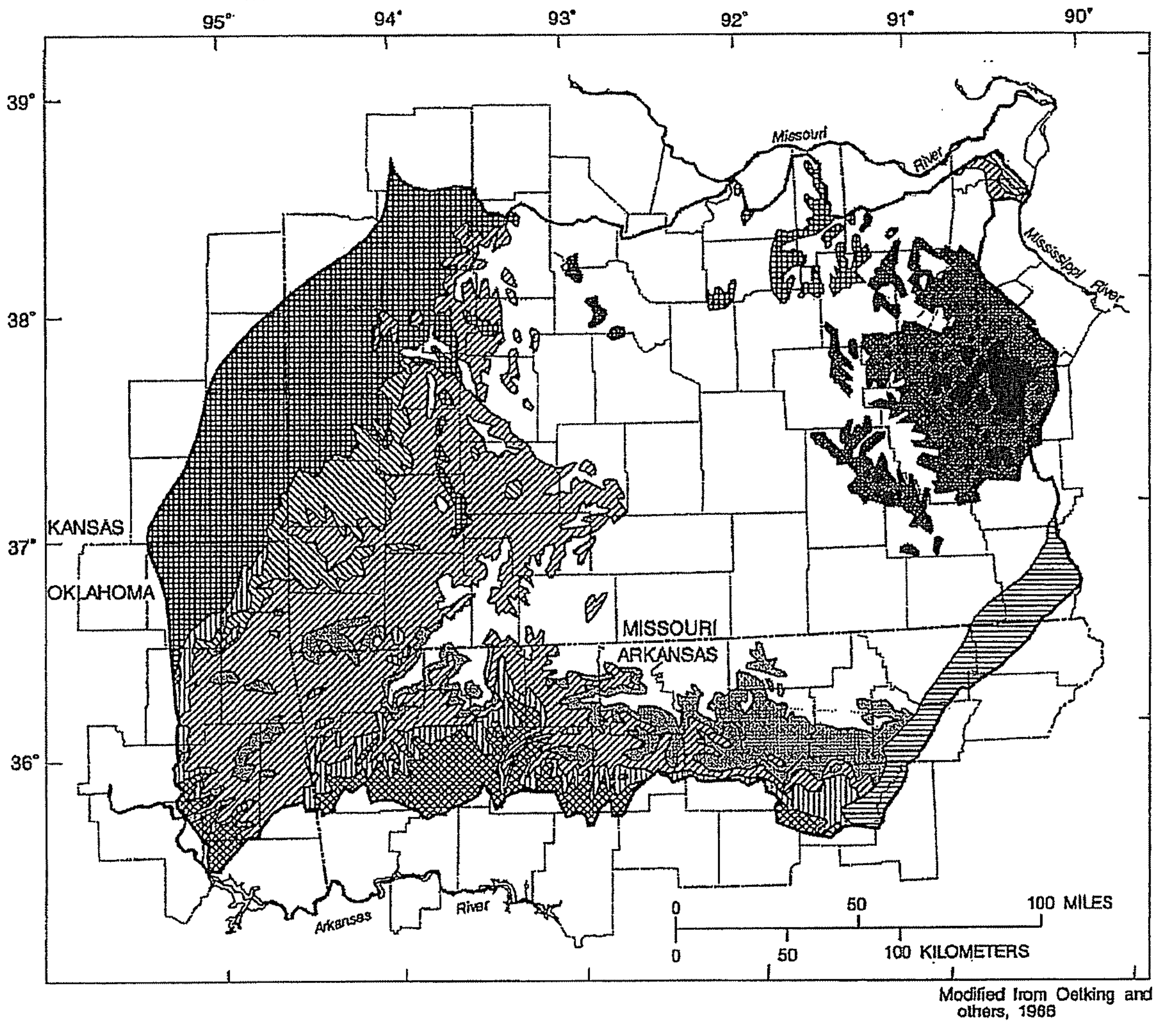


EXPLANATION

POST-PALEOZOIC SEDIMENTS

PENNSYLVANIAN--Cherokee, Marmaton, Pleasanton, and Kansas City Groups

PENNSYLVANIAN (MORROWAN-ATOKAN)--Hale, Bloyd, and Atoka

MISSISSIPPIAN (CHESTERIAN)--Carterville, Hindsville, Batesville, Fayetteville, and Pitkin

MISSISSIPPIAN (MERAMECIAN)--Warsaw, Salem, St.Louis, and Moorefield

MISSISSIPPIAN (KINDERHOOKIAN-OSAGEAN) Compton, Sedalia, Northview, Chouteau, Pierson, Fern Glen, St. Joe, Boone, Reeds Spring, Elsey, Burlington, and Keokuk

MIDDLE ORDOVICIAN THROUGH DEVONIAN--Everton, Burgen, St. Peter, Joachim, Tyner, Plattin, Viola, Kimmswick, Fernvale, Sylvan, Carson, and Chattanooga

LOWER ORDOVICIAN--Gunter, Gasconade, Roubidoux, Jefferson City, Cotter, Powell, and Smithville

CAMBRIAN--Lamotte, Reagan, Bonneterre, Davis, Derby-Doe Run, Potosi, and Eminence

PRECAMBRIAN IGNEOUS ROCKS

STUDY UNIT BOUNDARY

Figure 8. Geology of the Ozark Plateaus study unit.

and others, 1972). These dolomites are relatively impermeable compared to the other units of Cambrian and Ordovician age (Imes and Emmett, 1994).

The Potosi and Eminence Dolomites, which represent the top of the Cambrian section, are fine- to coarse-grained dolomites with dense chert, drusy quartz, and, in northern Arkansas, glauconitic green shale (Caplan, 1960). These units are exposed in southeastern Missouri. Thicknesses of the Potosi and Eminence Dolomites in Missouri average about 300 to 350 ft each (Howe and others, 1972), but total thickness for the two formations combined diminishes to 300 ft in northern Arkansas (Caplan, 1960). Both units contain barite, which has been mined in southeastern Missouri (Wharton and others, 1975).

The Gasconade Dolomite consists of a basal sandstone member, the Gunter Sandstone, and upper and lower dolomite members (MacDonald and others, 1975). It crops out extensively in southeastern Missouri. The Gunter Sandstone Member is a fine- to coarse-grained quartz sandstone, which can be dolomitic (Caplan, 1960). Thickness ranges from 30 to 120 ft. Chert is present in both dolomite members and can constitute more than 50 percent of the lower member. The upper dolomite member contains much less chert than does the lower member. Thickness of the Gasconade Dolomite ranges from 300 ft in central Missouri to more than 700 ft in northern Arkansas (MacDonald and others, 1975).

The Roubidoux Formation consists of sandstones, dolomites, and cherty dolomites (Thompson, 1991). It crops out extensively in central, south-central, and southeastern Missouri. The dolomites are fine to medium grained, and the sandstones are loosely cemented. In northern Arkansas, it can contain a few pyritic black shales. Thickness generally increases to the south-southeast and ranges from 100 to 450 ft (Caplan, 1960; Thompson, 1991).

The Jefferson City, Cotter, and Powell Dolomites, and the Smithville Formation consist of dolomite with chert, sandstone lenses, and a few shale beds. These units are pyritic, and the Smithville Formation contains lead and zinc ore. The units are exposed in southern Missouri and northern Arkansas (Caplan, 1960). Thickness of each unit averages about 200 ft (MacDonald and others, 1975).

The Everton Formation contains sandy dolomite and sandstone members, which crop out extensively in northern Arkansas. It contains a few shale beds, none of which are laterally continuous. It can exceed 1,000 ft in thickness (Frezon and Glick, 1959).

The St. Peter Sandstone unconformably overlies the Everton Formation and crops out mainly in northern Arkansas. It is a loosely cemented, well-rounded quartz sandstone that can be as much as 300 ft thick (McFarland and others, 1979). Its contact with the overlying Joachim Dolomite is lithologically gradational (Frezon and Glick, 1959).

Silurian and Devonian Units

Rocks of Silurian and Devonian age are thin, and most are not laterally continuous in the study unit. Most of the units in this interval exist only in northern Arkansas and parts of Missouri. The most significant unit is the black, pyritic, thinly bedded Chattanooga Shale. This shale ranges in thickness from less than 10 to 100 ft, but averages about 70 ft in thickness (Wise and Caplan, 1979). It contains phosphate, glauconite (Frezon and Glick, 1959), and minor amounts of uranium (Nuelle, 1987).

Mississippian Units

Rocks of Mississippian age in the study unit are predominantly fine- to coarse-grained limestones and cherty limestones. These units have a total thickness of about 200 to 500 ft (McFarland and others, 1979) and crop out extensively in the Springfield Plateau (fig. 8).

Because of lateral facies changes and independent geologic studies in different states, the same sequence of rocks has different nomenclature throughout the study unit. For example, the St. Joe Limestone and the Boone Formation in northern Arkansas are equivalent to the entire sequence from the Compton Limestone to the Keokuk Limestone in southern Missouri.

As with the underlying rocks of Cambrian and Ordovician age, secondary mineralization is extensive in the limestones of Mississippian age. Lead- and zinc-sulfide deposits are present in southwestern Missouri, southeastern Kansas, and northeastern Oklahoma. Pyrite, lead and zinc carbonates, and zinc silicates are also present in these deposits (Kiilsgaard and others, 1967).

Rocks of late Mississippian age overlie the Boone Formation and equivalent units and crop out on the northern flank of the Boston Mountains. These units include the relatively permeable Hindsville and Pitkin Limestones, which are separated by the thick, impermeable Fayetteville Shale. The Fayetteville Shale is a fissile, pyritic, and carbonaceous shale with abundant iron concretions. In north-central Arkansas, the shale is interbedded with thin layers of finely crystalline limestones (McFarland and others, 1979).

Pennsylvanian Units

Rocks of Pennsylvanian age crop out in the Boston Mountains of northern Arkansas, and in the Osage Plains of western Missouri, southeastern Kansas, and northeastern Oklahoma (fig. 8). In general, rocks of Pennsylvanian age rest unconformably on rocks of Mississippian age; however, in the north-central part of the study unit, rocks of Mississippian age are missing, and rocks of Pennsylvanian age directly overlie rocks of Ordovician age (fig. 8).

In northern Arkansas, three geologic units--the Hale Formation, the Bloyd Shale, and the Atoka Formation--are of Pennsylvanian age. The Hale Formation and Bloyd Shale are massive sandstones with limestone, shale, and coal beds. The Atoka Formation is mostly dark shales with sandstones and sandy limestones (Caplan, 1957). Total thickness of the section in the southern part of the study unit ranges from 1,000 to 2,000 ft (Imes, 1990g).

Rocks of Pennsylvanian age in western Missouri, southeastern Kansas, and northeastern Oklahoma consist of four groups--Cherokee, Marmaton, Pleasanton, and Kansas City--and have a combined thickness that ranges from 40 to 700 ft. Lithologies are mostly shales and sandstones with some limestones. Black shales in the section can be uranium-bearing (Coveney and others, 1987). Bituminous coal beds are present in the Cherokee and Marmaton Groups (Robertson and Smith, 1981). In places, these same units produce oil and gas (Anderson and Wells, 1967).

Post-Paleozoic Units

Sediments of Cretaceous through Quaternary age in the study unit consist of unconsolidated sands, gravels, and clays. These sediments crop out in the Mississippi Alluvial Plain and as thin alluvial deposits in some of the major stream valleys (fig. 8; Fenneman, 1938).

Structural Geology

The Ozark Plateaus Province is underlain by a structural dome formed by a series of uplifts that has occurred since Precambrian time. Total uplift is approximately 5,000 ft (McCracken, 1967).

The dome is asymmetrical; the dip of sedimentary rocks is greater to the east-southeast than it is to the south, west, or north (McCracken, 1967). For example, regional dip east of the St. Francois Mountains is 150 ft/mi (feet per mile; Tikrity, 1968), whereas regional dip in southwestern Missouri is about 10 ft/mi. The dip to the south increases to 200 ft/mi on the southern flank of the Boston Mountains as a result of faulting in the area (Frezon and Glick, 1959).

Extensive fracturing, jointing, and faulting of the rocks has resulted from the uplifting. Photo-lineament analyses of the Boone Formation in northwestern Arkansas indicate that fractures generally trend northwest, northeast, and east-west (Ogden, 1980; Adamski, 1987; Leidy and Morris, 1990). Joints are present in many of the rocks of Paleozoic age. Joints trend east-west, north-south, northwest-southeast, and northeast-southwest. Dip of these joints generally is vertical (McCracken, 1971).

Major faults in the Ozark Plateaus trend northwest (McCracken, 1967). Displacement can be as much as 1,000 ft. Some of the major faults form escarpments visible for several miles (Beveridge and Vineyard, 1990).

Several distinct ring-shaped fault systems exist in the Ozark Plateaus of Missouri. One such structure, the Decaturville Structure in Camden County, Missouri, is about 4 mi in diameter. It consists of a pegmatite of Precambrian age exposed in the center and surrounded by rocks of Ordovician age (Offield and Pohn, 1979).

Geological History

Granite and rhyolite rocks of Precambrian age crystallized about 1.2 to 1.5 billion years ago in the Ozark Plateaus and adjacent areas (Tikrity, 1968). These igneous rocks form the basement complex of the study unit. After igneous activity ceased, the landscape was eroded prior to Late Cambrian time when the Lamotte Sandstone and Bonneterre Dolomite were deposited (McCracken, 1971). Deposition of marine carbonates was nearly continuous, with brief periods of erosion and deposition of clastic sediments, from Late Cambrian to Middle Ordovician time (Frezon and Glick, 1959). The area was extensively eroded prior to the deposition of the Everton Formation (C.E. Robertson, Missouri Division of Geology and Land Survey, written commun., 1992).

After deposition of the Everton Formation, the Ozark Plateaus area was uplifted and the sediments were extensively eroded. Geologic units from the St. Peter Sandstone through Fernvale Limestone were subsequently deposited, but uplifting limited sediment deposition from Middle Ordovician to Early Devonian time. After the Early Devonian time, the Ozark Plateaus area was uplifted again and eroded (McCracken, 1971).

Sediments of Middle Devonian and Mississippian age were subsequently deposited in the study unit. Limestones of Mississippian age were deposited in shallow seas that inundated the Ozark Plateaus area. After Mississippian time, the northern part of the Ozark Plateaus area was uplifted and tilted. Rocks of Devonian and Mississippian age were beveled, exposing rocks of Ordovician age over much of the area (Frezon and Glick, 1959; McCracken, 1971).

Sediments of Pennsylvanian age were deposited by transgressing seas and by riverine systems, in places, directly on the exposed rocks of Ordovician age. Periodic uplifts formed unconformities in the rocks of Pennsylvanian age. The Ozark Plateaus area was uplifted and extensively eroded after Pennsylvanian time (McCracken, 1971).

The fluvial and marine sediments were deposited in Late Cretaceous and early Tertiary time. Subsequent uplifting exposed the area to erosion, generating the current topography (McCracken, 1971).

Soils

Three types of soils--mollisols, alfisols, and ultisols--underlie most of the study unit (fig. 9). Mollisols, which are the dominant soil in the Osage Plains, form under prairies on sandstones, limestones, and shales (Persinger, 1977). These soils are agriculturally productive, having thick, dark upper horizons that are dominated by divalent cations. This horizon has a crumbly or granular texture (Brady, 1984).

Alfisols and ultisols are the dominant soil types underlying the Ozark Plateaus and the Mississippi Alluvial Plain (Allgood and Persinger, 1979). These soil types, which generally form under deciduous forests in warm, humid climates, are moderately to strongly weathered. These soils commonly contain an abundance of kaolinite, illite, and iron and aluminum oxides, are depleted in organic matter, and can be acidic (Brady, 1984).

Soil series in the study unit are extremely diverse; therefore, it is difficult to generalize hydrologic characteristics. In Boone County, Arkansas, for example, parts of which lie in the Boston Mountains, Springfield Plateau, and Salem Plateau, 19 soil series have been identified. Soil thickness for these series ranges from 0 to 84 in., permeability ranges from 0.06 to 6.00 in/hr (inches per hour), and pH ranges from 3.6 to 8.4 (Harper and others, 1981). In Benton, Fulton, Izard, and Newton Counties, Arkansas, organic matter constitutes from 0.2 to 6 percent of the soil (Phillips and Harper, 1977; Ward and Rowlett, 1984; Fowlkes and others, 1988).

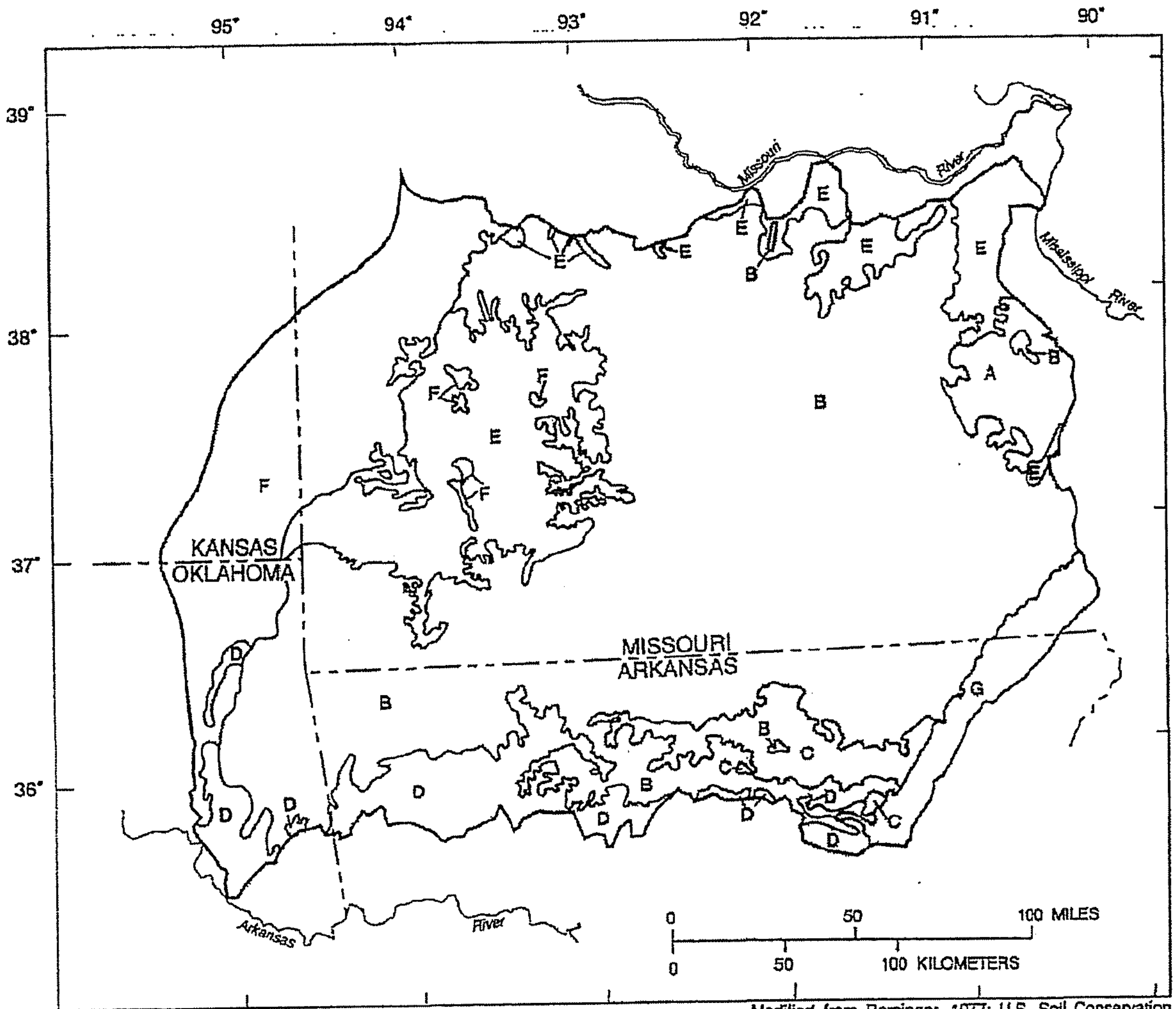
In general, most of the soils in the study unit have a high potential for nutrients and other dissolved constituents to be leached to the ground water and have a high potential for runoff to surface water systems. Leaching potential is high for 65 percent of the soils in Boone County, Arkansas; runoff potential is severe for 38 percent of the soils (Rick Fielder, U.S. Soil Conservation Service, written commun., 1992). In addition, erosion potential is moderate to high for soils in the Ozark Plateaus. Erosion factors range from 0.10 to 0.49 in Boone, Fulton, Izard, and Newton Counties, Arkansas (Harper and others, 1981; Ward and Rowlett, 1984; Fowlkes and others, 1988). Erosion factors greater than 0.40 are considered high (Rick Fielder, oral commun., 1992).

In places, several diverse soil series are closely associated and, therefore, difficult to map separately. Arkana and Moko soil series account for nearly 22 percent of the soils in Boone County, Arkansas. Arkana soils have a low leaching potential and a moderate runoff potential. Moko soils have a high leaching potential and a severe runoff potential. In 91 percent of the total area of distribution, Arkana and Moko soils are closely associated, forming a combined soil with diverse hydrologic characteristics (Harper and others, 1981).

Population

The 1990 population within the Ozark Plateaus study unit was approximately 2.3 million people. In the study unit, the population distribution was about 1.6 million in Missouri, 420,000 in Arkansas, 150,000 in Oklahoma, and 81,000 in Kansas (fig. 10; U.S. Department of Commerce, Bureau of Census, 1990).

Population in the study unit increased about 28 percent between 1970 and 1990. Counties having pop-



Modified from Persinger, 1977; U.S. Soil Conservation Service, 1982; Gray, 1959; U.S. Soil Conservation Service, 1986

EXPLANATION

SOIL TYPES

- A OZARK DOME–Alfisols and Ultisols
- B OZARK HIGHLANDS (DOLOMITES)–Alfisol and Ultisols
- C OZARK HIGHLANDS (SANDSTONES AND LIMESTONES)–Ultisols, Alfisols, and Mollisols
- D BOSTON MOUNTAINS–Ultisols and Alfisols
- E OZARK BORDER–Ultisols and Alfisols
- F OZARK PLAINS–Mollisols and Alfisols
- G MISSISSIPPI ALLUVIAL PLAIN–Alfisols and Ultisols

——— STUDY UNIT BOUNDARY

Figure 9. Major soil types of the Ozark Plateaus study unit.

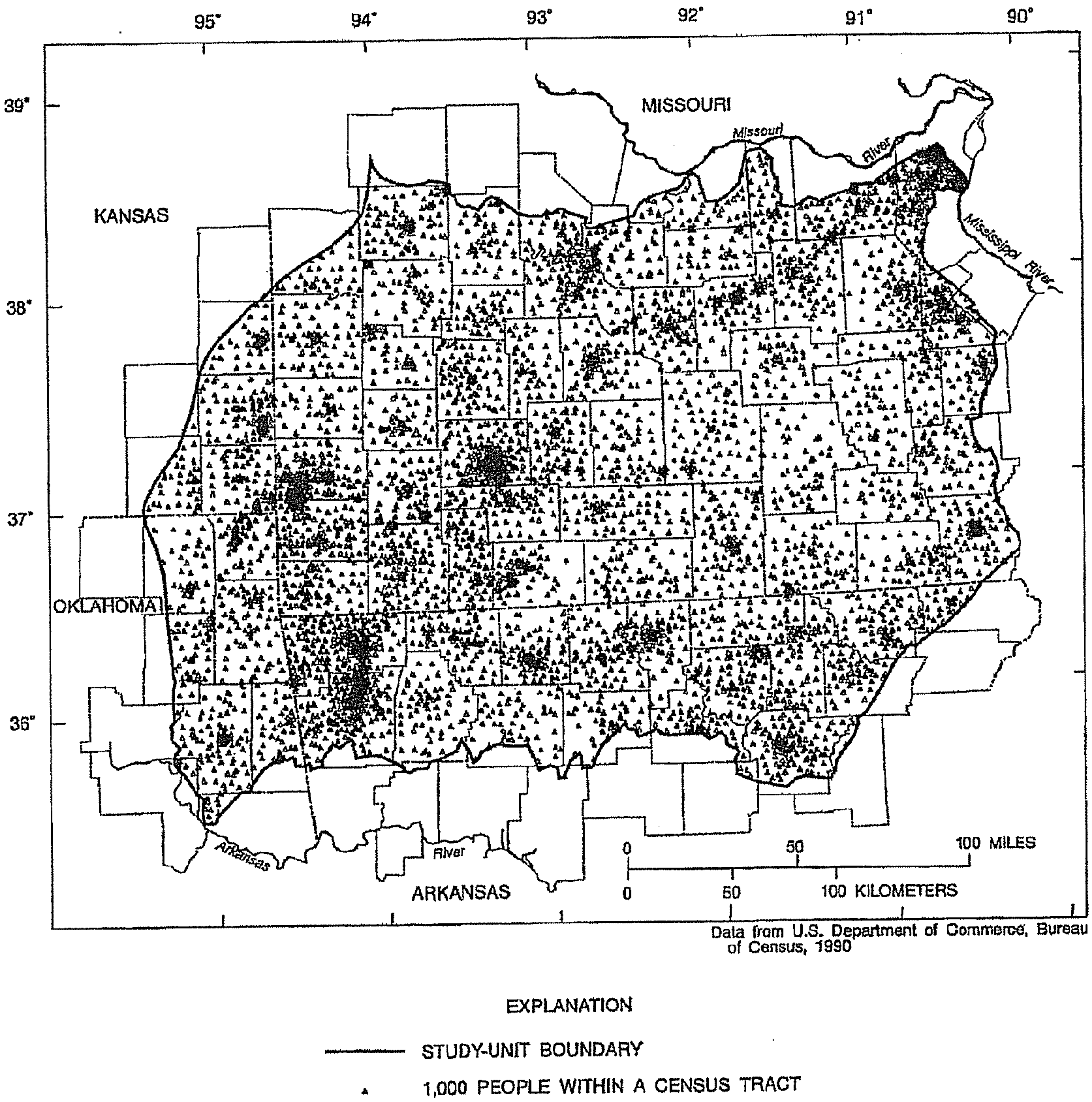


Figure 10. Population distribution in the Ozark Plateaus study unit, 1990.

ulation increases of 25, 50, 75, and 90 percent since 1970 are shown in figure 11. The largest percentage increases in population within the study unit were in southern Missouri and northern Arkansas. The population of some counties in northern Arkansas has increased more than 50 percent, and the population of several counties in southern Missouri has increased 90 percent in the last two decades.

Recreational activities attract many tourists to southern Missouri and northern Arkansas during the spring, summer, and fall. For example, Branson, Missouri (fig. 11), which has a resident population of only 3,700 people, was visited by an estimated 4.2 million tourists in 1991 (U.S. Department of Commerce, Bureau of Census, 1990).

Large urban areas are not common in the study unit. Springfield, Missouri, is the only city in the study unit with a population exceeding 100,000 people. The only urban areas in the study unit having populations exceeding 20,000 residents are Joplin, Missouri, and Fayetteville, Rogers, and Springdale, Arkansas (fig. 11; table 2; U.S. Department of Commerce, Bureau of Census, 1990).

Table 2. Population of the largest cities within the Ozark Plateaus study unit

[Source: U.S. Department of Commerce, Bureau of Census, 1990]

City	Population, 1990
Springfield, Missouri	140,494
Fayetteville, Arkansas	42,099
Joplin, Missouri	40,961
Springdale, Arkansas	29,941
Rogers, Arkansas	24,692

Land Use

Land use in the Ozark Plateaus and adjacent areas prior to European settlements was primarily oak-hickory forests on the hilly regions and bluestem prairie on the undissected plateaus. The upland forests generally consisted of old-growth oak-hickory or oak-hickory-shortleaf pine stands. Lowland forests had a greater variety of species than upland forests and included sycamores, cottonwoods, maple, black walnut, butternut, hackberry, poplar, and bur oaks. Prairies were common only in small patches in the eastern part of the Ozark Plateaus but about 50 percent of the western part was in prairie grasslands. The prairie vegetation was primarily composed of bluestem grasses. Trees were not well established in these prairies because Native Americans periodically burned the vegetation to drive game. Early settlers continued the practice of burning to provide pastureland; after the Civil War, however, many of the prairies were allowed to revert to forests (Rafferty, 1980).

A majority of the woodlands of the Ozarks Plateaus study unit are now second or third growth due to intense logging through the years. However, tree species in the woodlands are similar to those of the old-growth forests.

Currently (1993) land use in the Ozark Plateaus study unit consists primarily of forest, pasture, and some cropland (fig. 12). Deciduous forestland, mostly oak and hickory trees, predominate in the Salem Plateau and Boston Mountains, which often is mixed with pine trees in the White River Basin. Pastureland, which is mostly fescue (used as hay) and Kentucky blue grass, is grown in the river bottoms and gentle to steep slopes of the uplands in the Springfield Plateau. Cropland is the predominant land use in the Osage Plains and Mississippi Alluvial Plain. Soybeans and sorghum with some corn, wheat, grains, and other field crops are grown in the Osage Plains, with rice dominating in the Mississippi Alluvial Plain.

Poultry, beef and dairy cattle, and swine are the dominant livestock raised in the pasturelands of the Ozark Plateaus study unit. Large concentrations of poultry farms are in the southwestern part of the study unit and in a small area around Miller County, Missouri. Intensive poultry farming started mainly around northwestern Arkansas in the 1930's and has expanded greatly into southwestern Missouri and northeastern Oklahoma in recent years (Rafferty, 1980). Dairy cattle farming is a major land use in the central part of the study unit. Commercial dairy farming grew rapidly from the early through the mid-1900's in southwestern Missouri and northwestern Arkansas. In recent years, dairy farming in the study unit has declined slightly. Beef cattle and hogs are raised throughout most of the study unit (Rafferty,1980).

Throughout much of the early and mid-1900's, mining was a major land use in parts of the Ozark Plateaus study unit. The study unit contains major deposits of lead, zinc, iron, barite, coal, and minor deposits of copper, silver, manganese, and tungsten and has a long

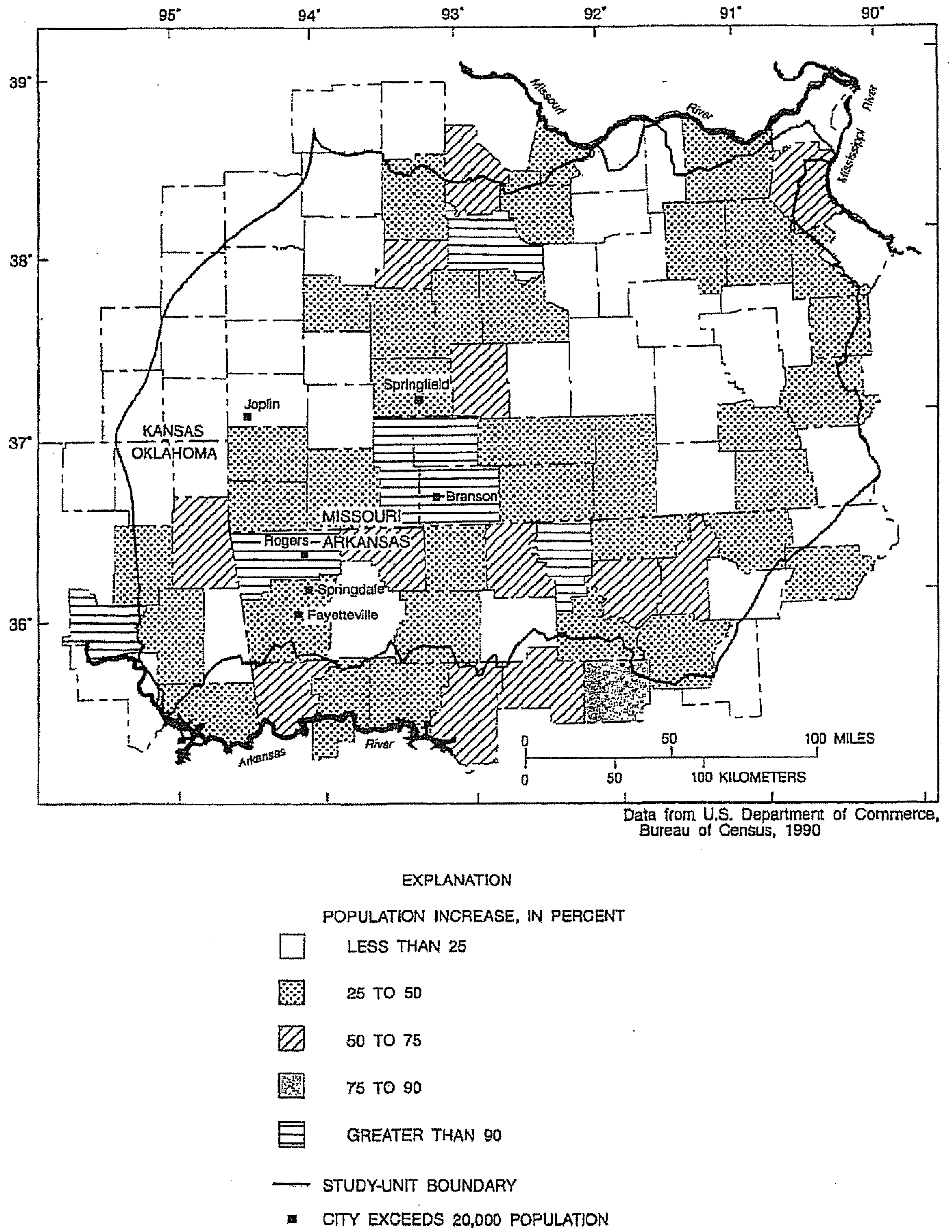


Figure 11. Percentage increase in population by county, 1970-90, and location of cities with 1990 population exceeding 20,000.

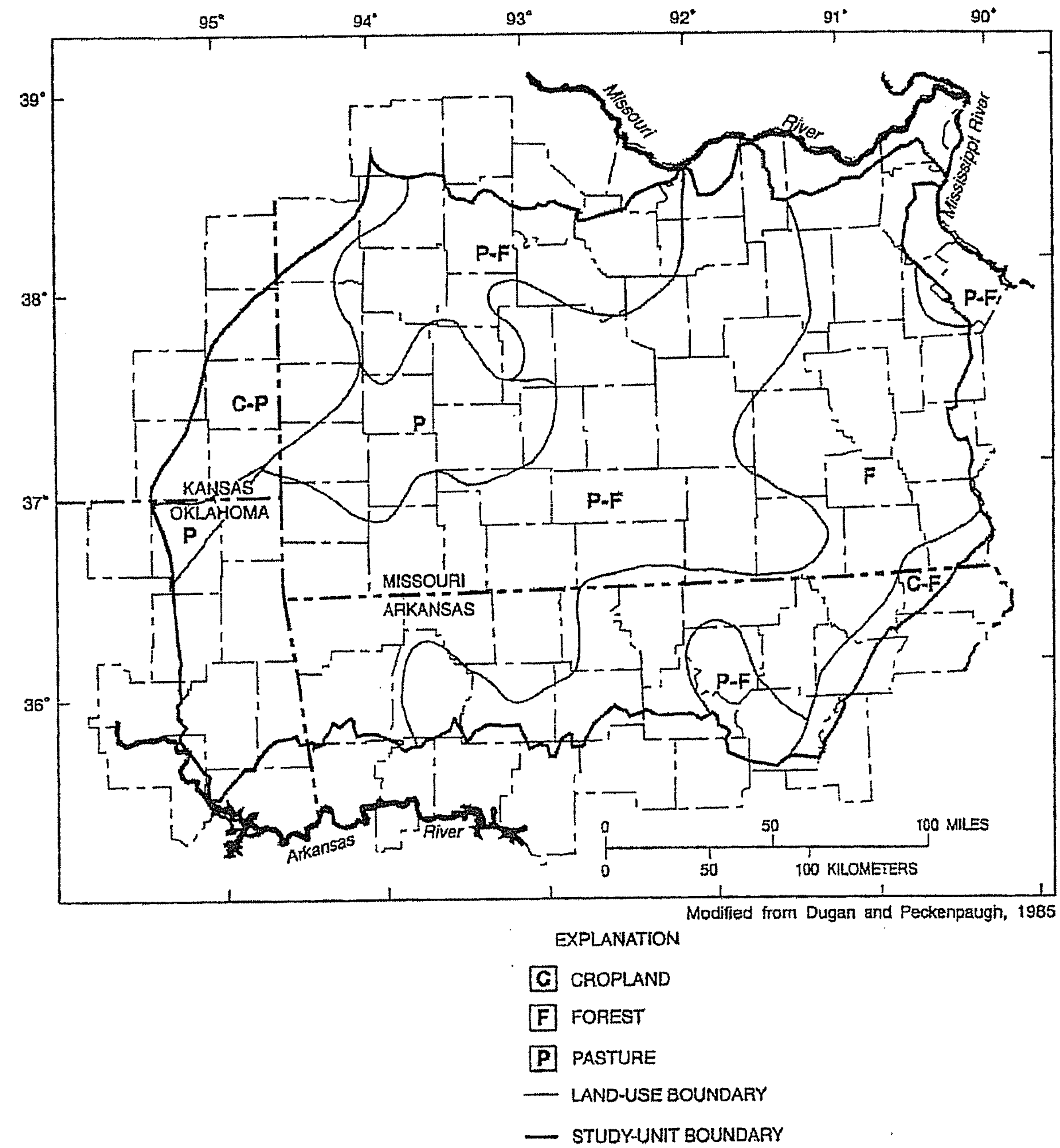


Figure 12. Generalized land use in the Ozark Plateaus study unit.

history as a major producer of lead and zinc. Mining activities in the study unit have occurred primarily in four main lead-zinc mining districts--the Southeastern District (Old Lead Belt, Viburnum Trend, and the Fredericktown subdistricts), the Tri-State District, the Central District, and the North Arkansas District (fig. 13). By far, the most important ore deposits were in the Tri-State District and the Southeastern District (Wharton and others, 1975). The Southeastern District was primarily a lead producer, and the Tri-State District was primarily a lead and zinc producer (Wharton and others, 1975). The Central and the North Arkansas Districts contained relatively small, scattered ore deposits that were not mined as actively as were deposits in the two major lead-zinc mining districts (Rafferty, 1980). The Viburnum Trend subdistrict is the only area still actively mined for lead and zinc (Wharton and others, 1975).

Bituminous coal deposits underlie the northwestern part of the study unit. The coal is present in numerous beds, all associated with rocks of Pennsylvanian age (Robertson and Smith, 1981). Historically, coal production in this area has fluctuated with national and international economic conditions. Until 1925, most of the coal was mined underground. Approximately two-thirds of the coal mined is used to produce electricity (Searight, 1967).

Water Use

Freshwater withdrawals or use from both surface- and ground-water sources within the Ozark Plateaus study unit averaged about 1,053 Mgal/d in 1990. A summary of water use for parts of Arkansas, Kansas, Missouri, and Oklahoma that are within the study unit is presented in table 3. Nonconsumptive withdrawals, such as water withdrawn by power generating plants, are not included in the data given in this table. Water use by county in the Ozark Plateaus study unit is shown in figure 14. Withdrawals within the study unit for counties only partly within the study unit were estimated from county totals and the percentage of the county within the study unit. Of the total water used in the study unit in 1990, approximately 58 percent was withdrawn from ground-water sources and 42 percent from surface-water sources. Ground-water use for irrigation accounted for 39 percent of the total, primarily for rice production from counties in the Mississippi Alluvial Plain. Surface-water use for public supply, primarily from reservoir systems in northwestern Arkansas, southwestern Missouri, and northeastern Oklahoma, accounted for 20 percent of the total water used in the study unit. Withdrawals for agriculture, commercial, domestic, industrial, and mining use categories were each less than 100 Mgal/d in 1990.

SURFACE WATER

Surface-water resources are abundant in the Ozark Plateaus study unit. Several major rivers and large reservoirs are located within the study unit. Most rivers flow radially away from the central part of the Springfield-Salem Plateaus or the Boston Mountains.

Major Rivers, Tributaries, and Reservoirs

The Ozark Plateaus study unit is drained by seven major river basins--the White, Neosho-Illinois, Osage, Gasconade, Meramec, Black, and St. Francis Rivers

Table 3. Water use within the Ozark Plateaus study unit, 1990

[SW, surface water; GW, ground water; units are million gallons per day. Source: Aggregated Water Use Data System (AWUDS) data base maintained by U.S. Geological Survey office in each state]

	Agriculture		Commercial		Domestic		Industrial		Irrigation		Mining		Public supply		Total		Total water use
State	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	
Arkansas	18	7	85	0	0	11	19	0	27	272	0	0	51	12	200	302	502
Kansas	2	1	0	0	0	0	4	0	1	0	0	0	4	6	11	7	18
Missouri	17	6	0	10	0	32	21	18	24	140	0	25	96	65	158	296	454
Oklahoma	9	1	0	0	0	4	0	0	4	0	0	0	57	4	70	9	79
	46	15	85	10	0	47	44	18	56	412	0	25	208	87	439	614	1,053

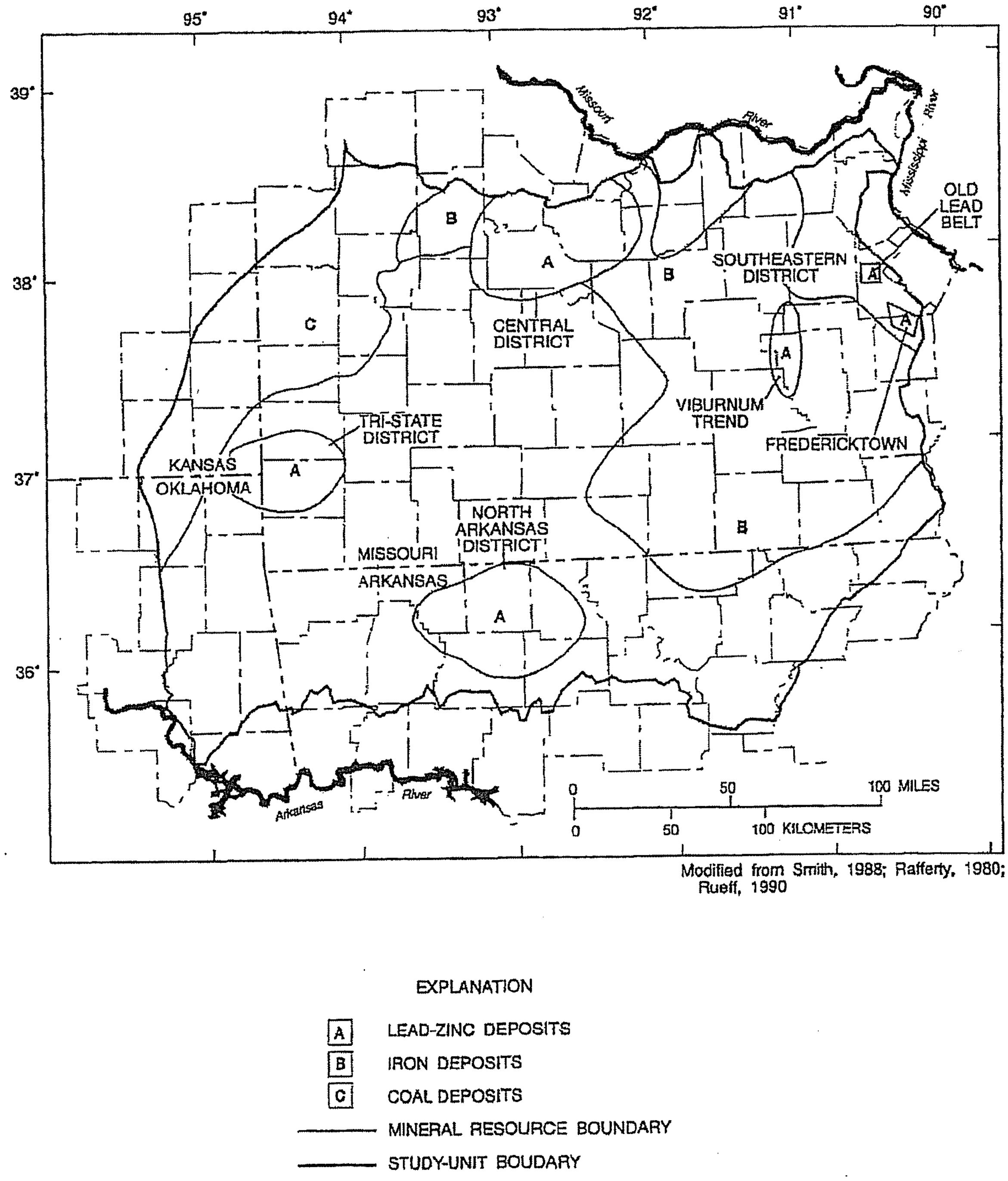
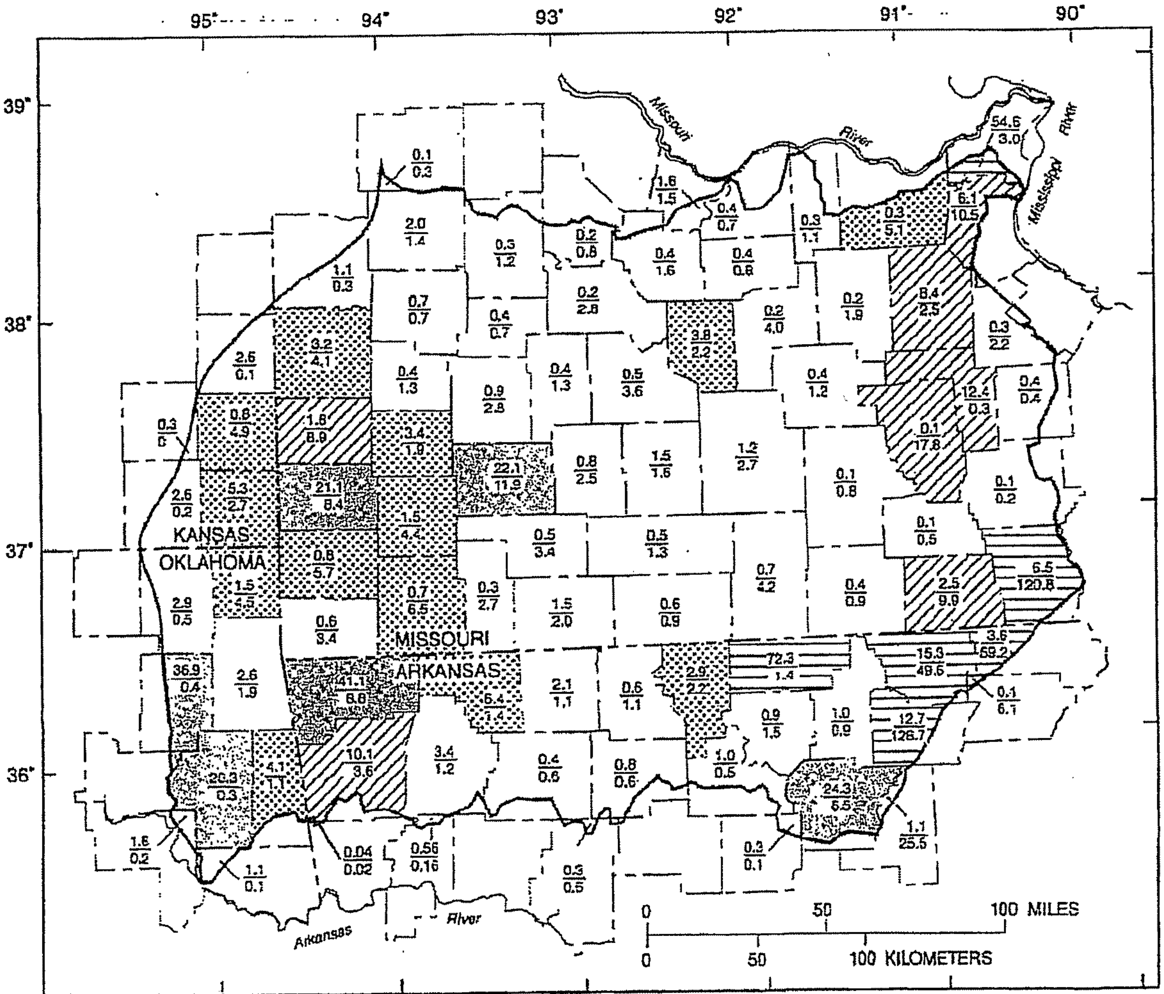


Figure 13. Mineral resources in the Ozark Plateaus study unit.



Data from U.S. Geological Survey

EXPLANATION

WATER USE, IN MILLION GALLONS PER DAY

$\frac{2.1}{1.1}$ SURFACE WATER / GROUND WATER

TOTAL SURFACE- PLUS GROUND-WATER USE, IN MILLION GALLONS PER DAY

- LESS THAN 5
- 5 TO 10
- 10 TO 20
- 20 TO 50
- GREATER THAN 50

STUDY-UNIT BOUNDARY

Figure 14. Water use by county in the Ozark Plateaus study unit, 1990.

(fig. 15; table 4)--that either directly or indirectly flow into the Mississippi River. The Black River is a tributary of the White River, which flows directly into the Mississippi River, as do the Meramec and St. Francis Rivers. The Neosho and Illinois Rivers are tributaries to the Arkansas River, which flows into the Mississippi River. The Osage and Gasconade Rivers flow into the Missouri River, which is the largest of the Mississippi River tributaries.

White River

The White River originates in the rugged terrain of the Boston Mountains of northwestern Arkansas, generally flows northward to the Arkansas-Missouri State line, then eastward through southern Missouri for about 115 mi where it intersects the State line again (fig. 15). The river meanders along the Arkansas-Missouri boundary for about 30 mi, flows southeastward into Arkansas to the mouth of the Black River (fig. 16), and then south to its confluence with the Mississippi River. The total drainage area of the White River is 27,800 mi^2, with about 10,600 mi^2 in southern Missouri and 17,200 mi^2 in northern and eastern Arkansas. About 11,300 mi^2 (not including the Black River Basin) are in the Ozark Plateaus study unit (Sullavan, 1974). The reach of the White River near the Arkansas-Missouri State line is a series of reservoirs, beginning with Beaver Reservoir in northwestern Arkansas and then proceeding downstream to Table Rock Lake, Lake Taneycomo, and Bull Shoals Lake. Norfork Lake is on a tributary to the White River downstream from Bull Shoals Lake. With the completion of Powersite Dam on the White River in 1912, Lake Taneycomo was the first major impoundment of water for power production in Missouri (U.S. Army Corps of Engineers, 1967). The areas near these lakes in both Arkansas and Missouri are increasingly popular recreational attractions and retirement areas.

Major tributaries to the White River in Arkansas are War Eagle Creek, Kings River, Crooked Creek, and Buffalo River. In 1972, the Buffalo River was designated the Buffalo National River by Congress (Public Law 92-237) "for the purposes of conserving and interpreting an area containing unique scenic and scientific features, and preserving as a free-flowing stream an important segment of the Buffalo River..." (Mott, 1991). Headwaters of War Eagle Creek, Kings River, and Buffalo River are in the Boston Mountains, but most of these basins lie within the Springfield Plateau (War Eagle Creek) or the Springfield and Salem Plateaus (Kings River and Buffalo River). Crooked Creek lies mainly in the Salem Plateau, but its headwaters are in the Springfield Plateau. Land use in this part of the White River Basin is primarily forest with pasture and some cropland.

The James and North Fork White Rivers are major tributaries to the White River in Missouri. Most of the James River Basin lies within the Springfield Plateau with the exception of the lower part of the basin where the James River or tributaries have incised rocks of Ordovician age in the Salem Plateau. The lower part of the basin is primarily forested, whereas the upper part is predominately pasture and cropland agriculture. Springfield, Missouri, the largest urban area in the study unit, lies within the James River Basin. The North Fork White River Basin lies entirely in the Salem Plateau and is about 70 percent forested. The lower part of the river has been impounded to form Norfork Lake.

Neosho-Illinois Rivers

The Neosho River originates in east-central Kansas in the gently rolling hills of the Osage Plains (fig. 15). Land in this part of the basin is used principally for cropland and pasture, although coal and lead-zinc mining has occurred in the basin. The river flows toward the southeast through Kansas into Oklahoma. Below the confluence with the Spring River, a major tributary, the river then follows a winding course through a chain of reservoirs before entering the Arkansas River (fig. 17). These reservoirs are popular recreational attractions. The lower part of the basin, which is predominantly in Missouri and Oklahoma, lies in the Springfield Plateau. The total drainage area of the Neosho River Basin is about 12,500 mi^2, but only about 60 percent of the drainage area (7,600 mi^2) is in the study unit. The largest urban area in the basin within the study unit is Joplin, Missouri. A major tributary to the Neosho River, the Elk River, lies entirely in the Springfield Plateau and drains pasture and forest in northern Arkansas and southwestern Missouri.

The Illinois River originates in northwestern Arkansas, flows generally to the north and then to the southwest into Oklahoma where it flows into the Arkansas River (fig. 17). The lower part of the river is impounded to form Tenkiller Ferry Lake. The basin (about 1,630 mi^2) lies entirely within the study unit and is mostly in the Springfield Plateau. The headwaters of the basin are in the Boston Mountains. From the Arkan-

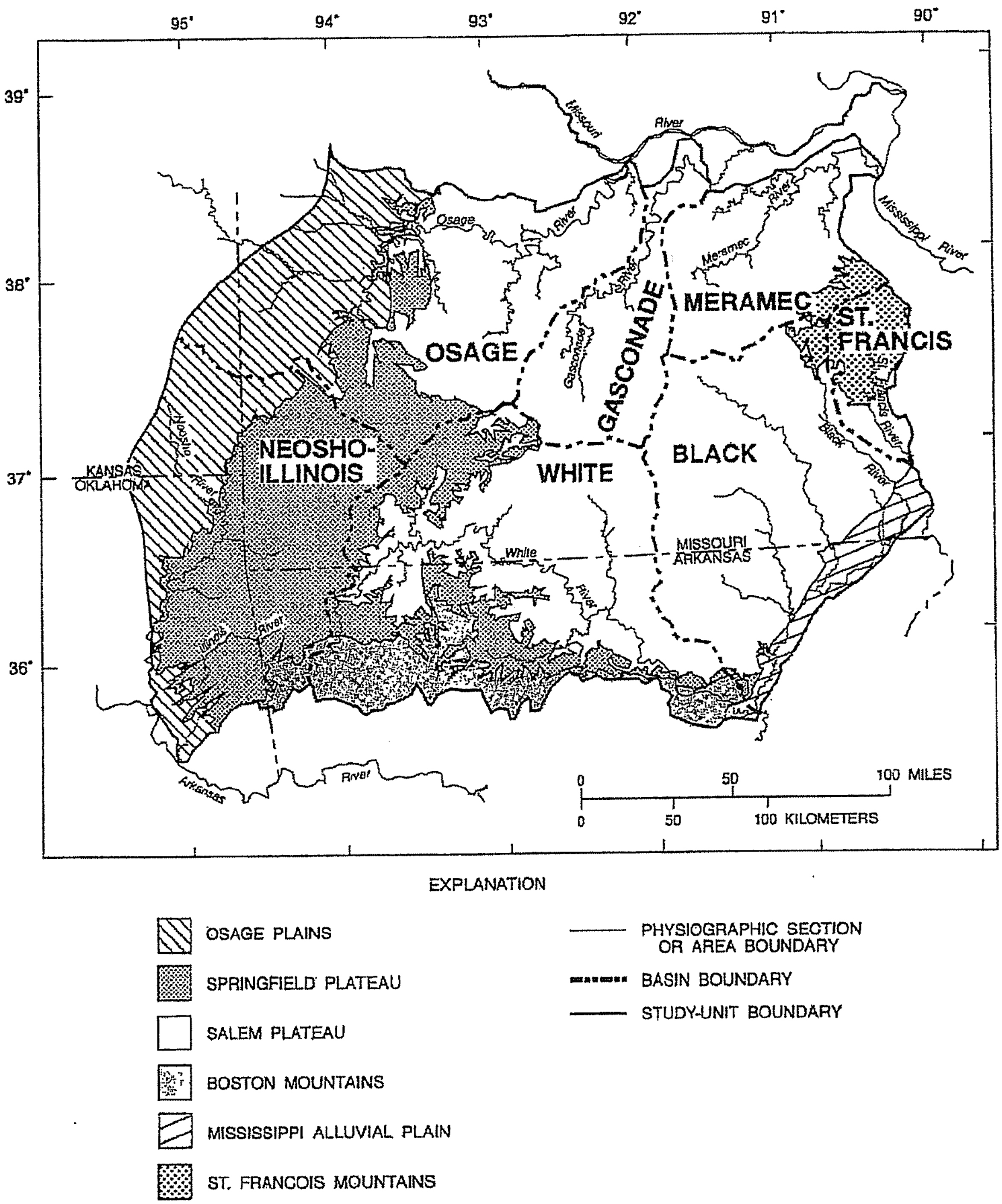


Figure 15. Major river basins and physiographic sections or areas in the Ozark Plateaus study unit.

Table 4. Summary of major tributaries, reservoirs, and land use in the major river basins in the Ozark Plateaus study unit

[Land use codes: F, forest; P, pasture; C, cropland; U, urban; M, mining; NA, not applicable]

River basin	Drainage area, in square miles: Total	Drainage area, in square miles: Study unit	Land use, in order of importance	Principal tributaries and drainage areas, in square miles		Principal reservoirs in the river basin
White River[1]	27,800	11,300	F, P, C, U	War Eagle Creek	332	Beaver Reservoir
				Kings River	565	Table Rock Lake
				Crooked Creek	462	Lake Taneycomo
				Buffalo River	1,340	Bull Shoals Lake
				James River	1,460	Norfork Lake
				North Fork White River	1,830	
Neosho-Illinois Rivers[2]	14,100	9,230	C, P, F, M	Spring River	2,510	Lake O' the Cherokees
				Elk River	872	Lake Hudson
				Big Cabin Creek	450	Fort Gibson Lake
				Osage Creek	206	Tenkiller Ferry Lake
				Baron Fork	307	
Osage River[3]	15,300	10,500	C, P, F, M	Little Osage River	570	Truman Reservoir
				Marmaton River	1,150	Lake of the Ozarks
				South Grand River	2,040	Stockton Lake
				Sac River	1,970	Pomme de Terre Lake
				Pomme de Terre River	828	
				Niangua River	1,040	
Gasconade River[4]	3,600	3,600	F, P	Big Piney River	760	None
				Osage Fork	520	
				Roubidoux Creek	300	
				Little Piney Creek	272	
Meramec River[5]	3,980	3,980	F, P, M	Bourbeuse River	841	None
				Big River	964	
St. Francis River[6]	6,480	1,310	F, P, M	NA	NA	Lake Wappapello
Black River[7]	8,560	8,560	F, P, M	Current River	2,610	Clearwater Lake
				Spring River	1,230	
				Eleven Point River	1,220	
				Strawberry River	792	

[1] Does not include the Black River Basin, which is the largest tributary of the White River. Drainage area for James River from Homyk and Jeffery (1967); all other drainage areas from Sullavan (1974). The drainage area for the Kings River does not include the small part of the basin in Missouri.

[2] Drainage areas for the Neosho River Basin determined at the following U.S. Geological Survey stations: (1) Neosho River below Fort Gibson Lake, near Fort Gibson, Oklahoma (07193500), (2) Spring River near Quapaw, Oklahoma (07188000), (3) Elk River near Tiff City, Missouri (07189000), and (4) Big Cabin Creek near Big Cabin, Oklahoma (07191000). Drainage area for Osage Creek from Terry and others (1984). Drainage areas for Baron Fork and Illinois River Basins determined at the following U.S. Geological Survey stations: (1) Illinois River near Gore, Oklahoma (07198000) and (2) Baron Fork at Eldon, Oklahoma (07197000).

[3] Drainage areas from Homyk and Jeffery (1967). About 960 mi^2 of the South Grand River Basin, 1,000 mi^2 of the Marmaton River Basin, and 270 mi^2 of the Little Osage River Basin are in the study unit. Drainage area for Little Osage River does not include the Marmaton River.

[4] Drainage areas from Homyk and Jeffery (1967).

[5] Drainage area for Meramec River Basin from Homyk and Jeffery (1967); drainage areas for Bourbeuse and Big Rivers from Missouri Department of Natural Resources (1984).

[6] Drainage area for the St. Francis River Basin from U.S. Geological Survey annual Water-Data Report; drainage area in the study unit determined at U.S. Geological Survey station St. Francis River at Wappapello, Missouri (07039500).

[7] Drainage areas from Sullavan (1974). Drainage area for Spring River does not include the Eleven Point River.

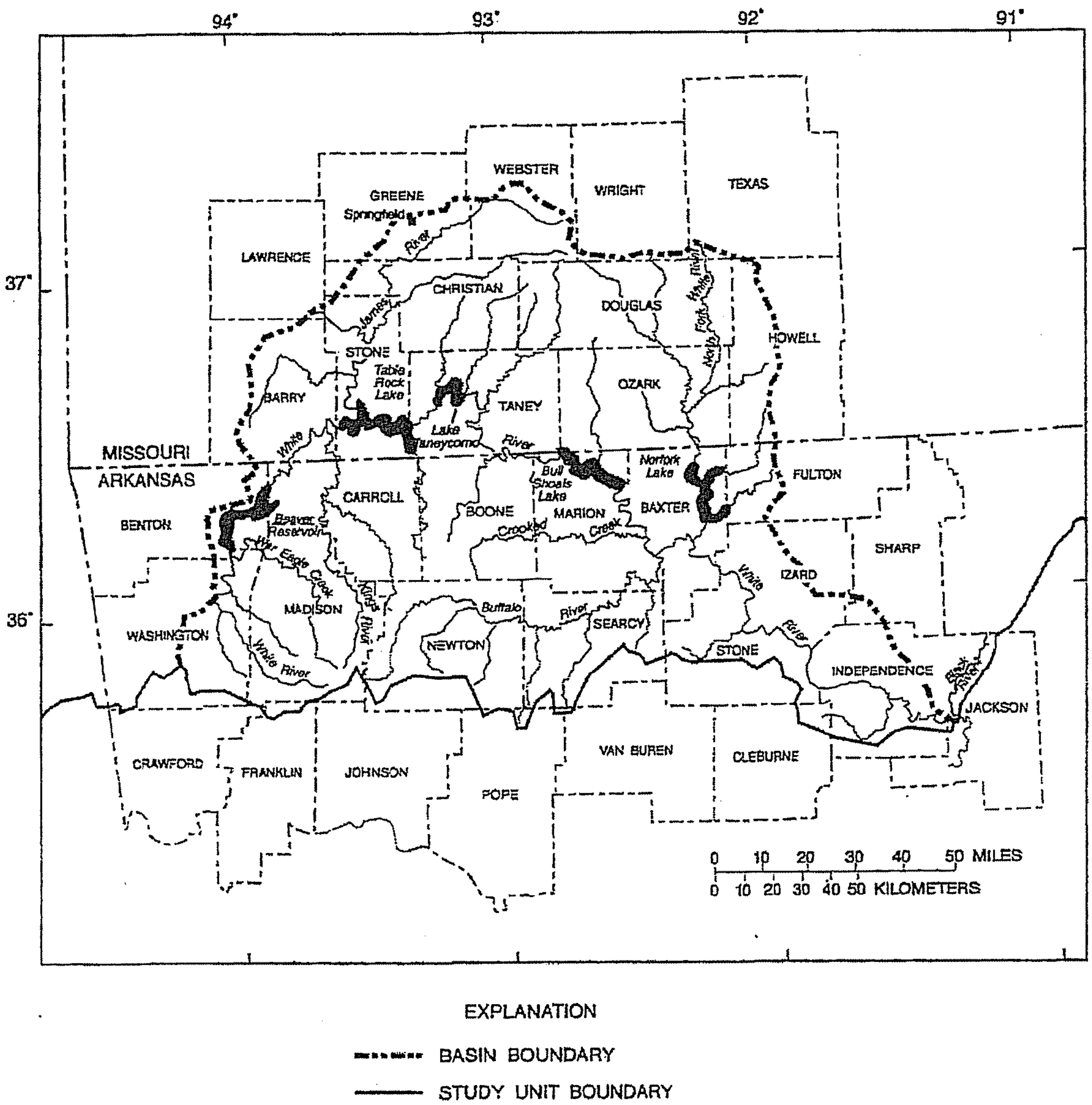


Figure 16. White River Basin with major tributaries and reservoirs.

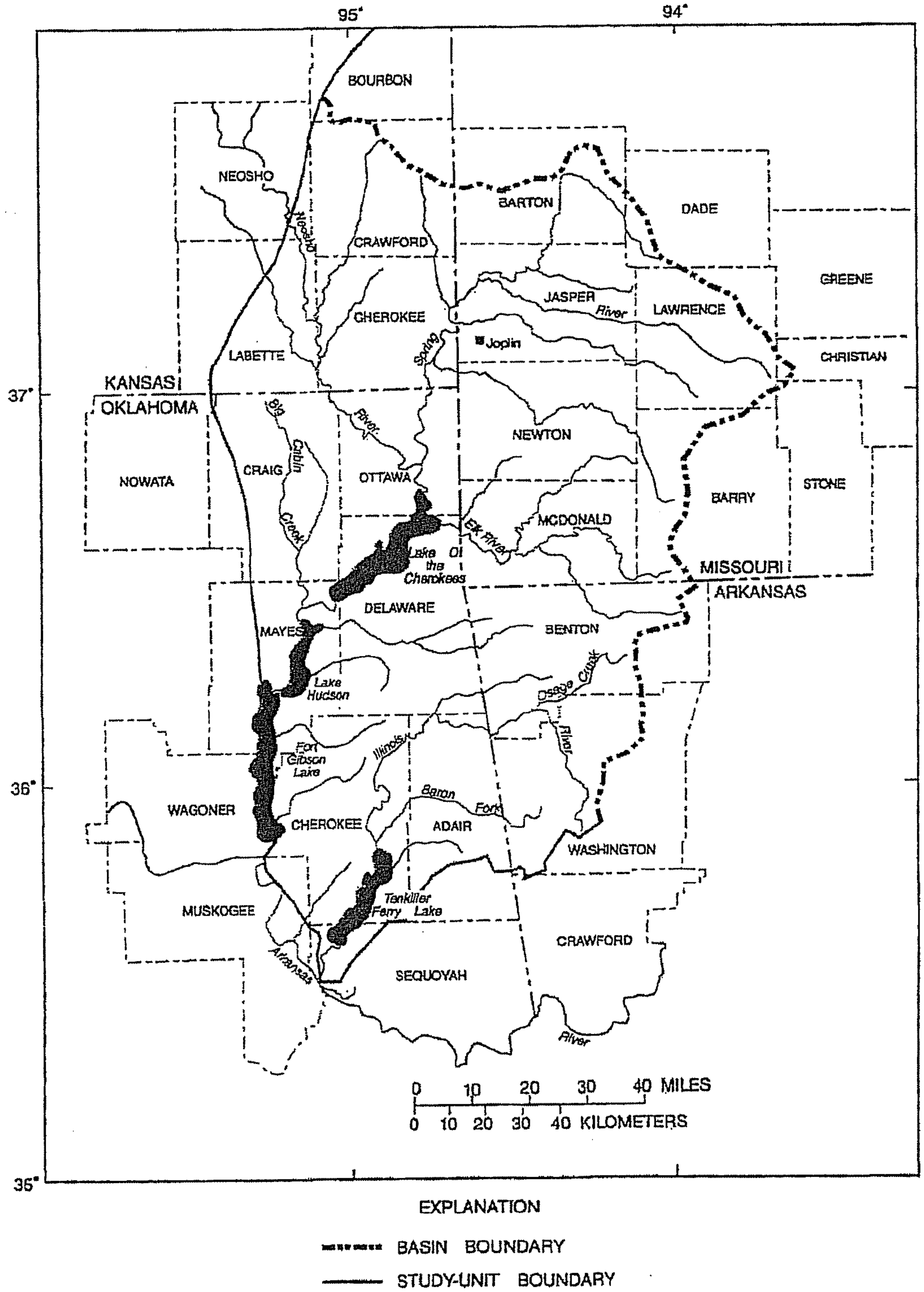


Figure 17. Neosho-Illinois River Basin with major tributaries and reservoirs.

sas-Oklahoma State line to the upper end of Tenkiller Ferry Lake, the Illinois River has been designated by the Oklahoma State Legislature as a scenic river and is the only river with this designation in Oklahoma.

Osage River

The Osage River originates in east-central Kansas and generally flows eastward into Missouri (fig. 15). In Kansas, the Osage River is called the Marais des Cygnes. The upper two-thirds of the Osage River system, including the Little Osage, Marmaton, and South Grand Rivers, drain the gently rolling prairie land of the Osage Plains (figs. 15 and 18). The South Grand River is the largest tributary to the Osage River and is the only major south-flowing tributary. Land use in this part of the basin is primarily cropland and pasture, although coal has been mined along the western study unit boundary.

The Osage River continues flowing eastward across the Springfield and Salem Plateaus to the Missouri River. About 602 mi of river have been inundated by the construction of four major reservoirs, including Truman Reservoir and Lake of the Ozarks on the main stem (Duchrow, 1984). As in the White and Neosho-Illinois River Basins, the lakes are popular recreational attractions and retirement areas. The total drainage area of the basin is 15,300 mi^2, with 10,700 mi^2 in Missouri and the remainder in Kansas. The drainage area for that part of the basin that lies in the study unit is about 10,500 mi^2.

The Sac River is the only tributary to the Osage River that lies entirely within the Springfield Plateau. Stockton Lake, the third major reservoir in the Osage River Basin, is on the Sac River. About one-half of the Sac River Basin is forested with the remaining land used primarily for cropland or pasture. A small part of this basin is urban. Withdrawals from two small public water-supply lakes and a spring in the Sac River Basin supply much of the drinking water for Springfield, Missouri, which lies on the drainage divide between the James and Sac River Basins.

The Pomme de Terre and Niangua Rivers are the two main Osage River tributaries that lie entirely within the Salem Plateau. Pomme de Terre Lake on the lower Pomme de Terre River is the fourth major reservoir in the Osage River Basin. The resident and tourist populations are not as large at Pomme de Terre Lake as at some of the other recreational reservoirs. Land use in nearly 50 percent of these two basins is agricultural, centered primarily around livestock production.

Gasconade River

The Gasconade River and its major tributary, the Big Piney River, generally flow toward the northeast through the rough terrain of the Salem Plateau to the Missouri River (figs. 15 and 19). No reservoirs or urban areas of any size are located in the basin, which is entirely within the study unit. The total drainage area of the Gasconade River Basin is 3,600 mi^2. At one time, parts of the Gasconade and Big Piney Rivers were considered for inclusion in the Wild and Scenic River System, but because of shoreline development, agricultural activities, and transportation corridors, some segments of the rivers did not meet the eligibility criteria (Bureau of Outdoor Recreation, 1973). The basin is about 75 percent forested; however, livestock and crop production are important land uses in the basin, particularly in the stream valleys.

Meramec River

The Meramec River Basin originates in the Salem Plateau in the northeastern part of the study unit and flows toward the northeast to the Mississippi River just south of St. Louis, Missouri (figs. 15 and 20). Maramec Spring, the seventh largest spring in Missouri, more than doubles the flow of the Meramec River in the upper part of the basin. The entire basin (3,980 mi^2) is in the study unit, with the exception of a small part in the St. Louis metropolitan area. The upper part of the basin is primarily forested with some cropland and pasture. Small tributaries to the upper Meramec River drain part of the Viburnum Trend mining area.

The Meramec River has two major tributaries, the Bourbeuse River on the north and the Big River on the east. Much of the basin of the Bourbeuse River, which flows from west to east along the northern part of the Meramec River Basin, is underlain by undifferentiated deposits of Pennsylvanian age, which overlie and sometimes fill depressions in an ancient karst topography developed in deposits of Ordovician age (Vineyard and Feder, 1974). The gently rolling terrain is suitable for agricultural land uses, and the Bourbeuse River Basin has more pasture and tilled lands than other parts of the Meramec River Basin. The Big River originates in the St. Francois Mountains and flows northward through the Salem Plateau to the Meramec River. The

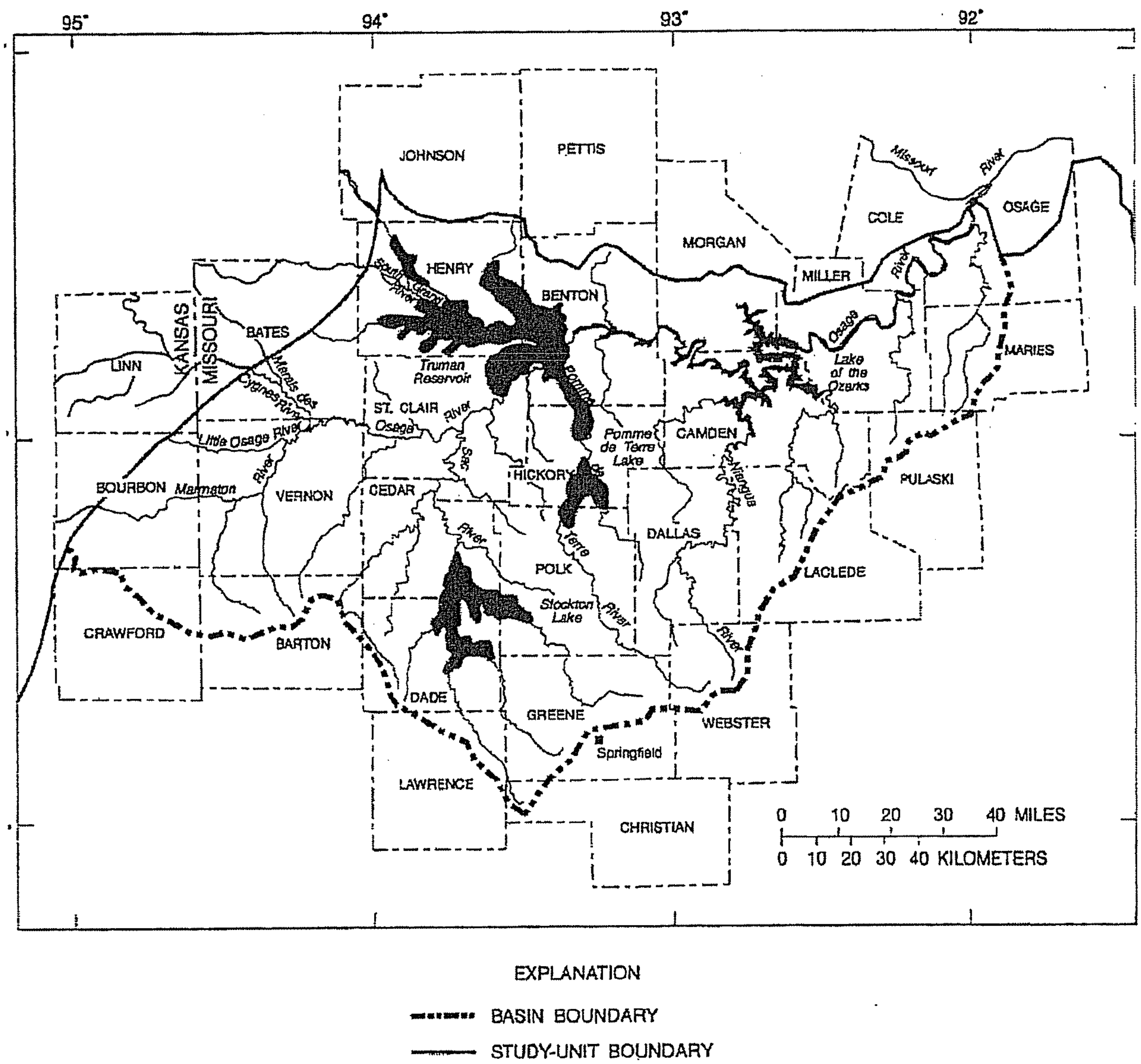


Figure 18. Osage River Basin with major tributaries and reservoirs.

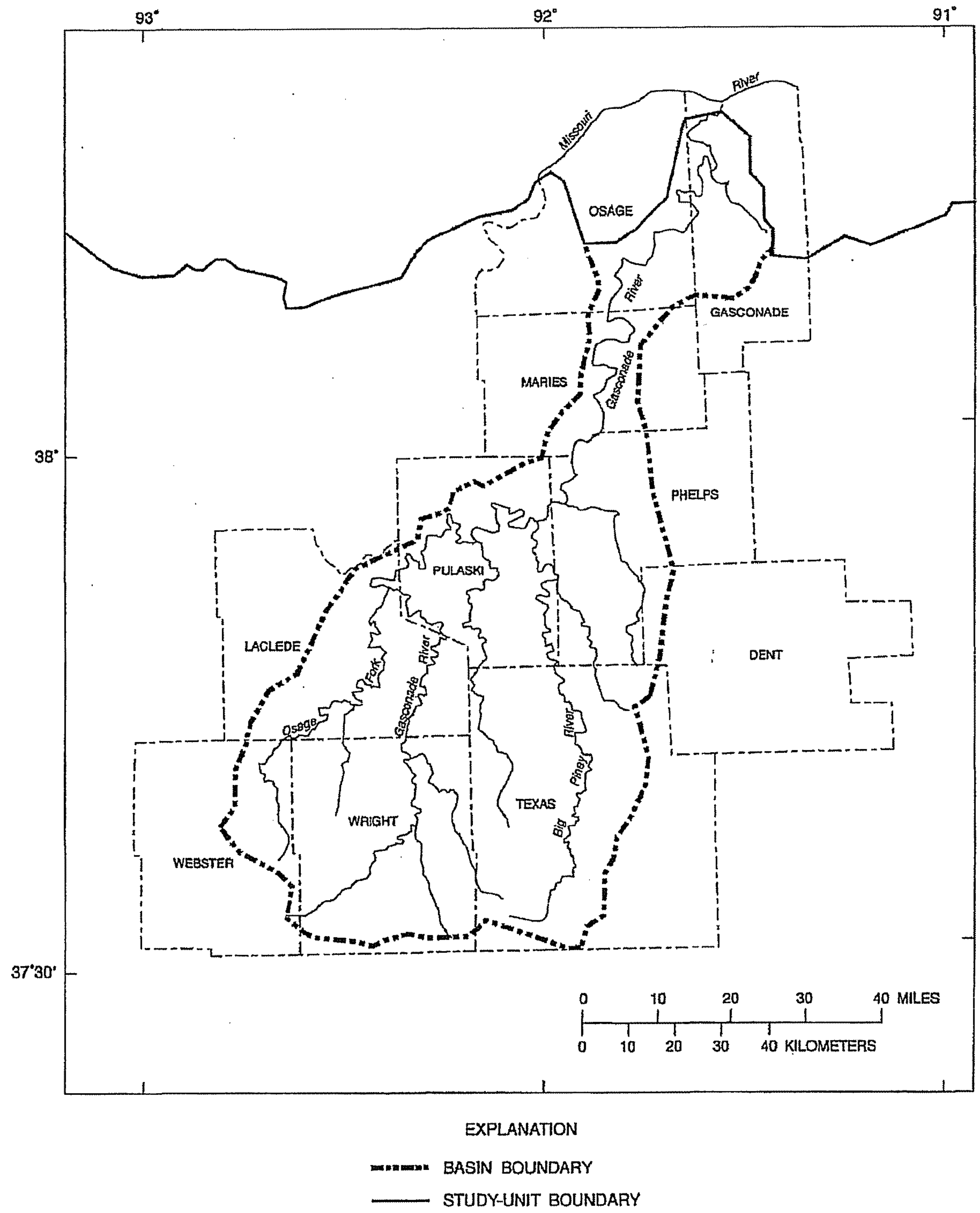


Figure 19. Gasconade River Basin with major tributaries.

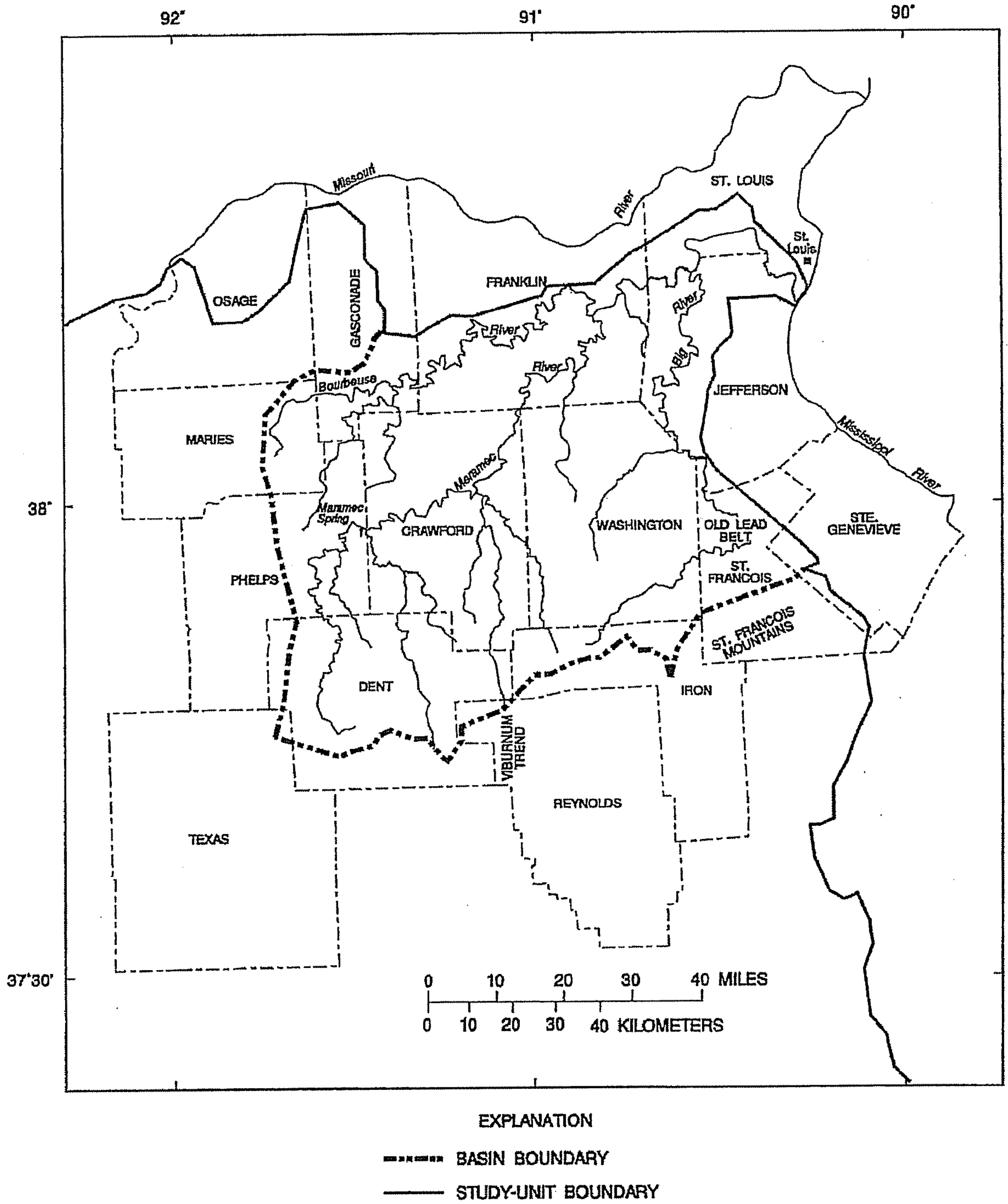


Figure 20. Meramec River Basin with major tributaries and spring.

Big River Basin encompasses much of the Old Lead Belt mining area and most of the area of past and present barite mining.

St. Francis River

The St. Francis River originates in the southern flank of the rugged St. Francois Mountains of southeastern Missouri and flows toward the south through the Salem Plateau out of the study unit into Arkansas to the Mississippi River (figs. 15 and 21). The total drainage area of the basin is about 6,480 mi^2, with only about 1,310 mi^2 in the study unit. Lake Wappapello, located at the southeastern extent of the basin in the study unit, is a major recreation area. Like other basins in the Salem Plateau, the basin is predominantly forested with some pasture, although some lead and zinc have been mined in the upper part of the basin.

Black River

The Black River is the largest tributary (8,560 mi^2) to the White River system. Major tributaries to the Black River include the Current, Eleven Point, Spring, and Strawberry Rivers. The Strawberry River Basin lies wholly in north-central Arkansas, but the headwaters and much of the drainage area of the other major tributaries of the Black River are in southern Missouri. Like the St. Francis River, the Black River originates on the southern flank of the St. Francois Mountains and flows southward through the Salem Plateau into Arkansas to the White River (figs. 15 and 22). On the eastern side of the river, a small part of the drainage area is in the Mississippi Alluvial Plain. The other tributaries lie entirely in the Salem Plateau. The only major reservoir in the basin, Clearwater Lake, is on the Black River in Missouri. At least 50 percent of the land is forested in all of the basins with the remainder used primarily for pasture and cropland; no major urban areas are in the Black River Basin. Small tributaries to the upper Black River drain the southern end of the Viburnum Trend mining area.

The Black River Basin is characterized by rugged, hilly countryside, numerous springs, and clear, fast-flowing streams. The three largest springs in the study unit are in the Black River Basin: Greer Spring (average flow of 289 ft^3/s) on the Eleven Point River, Mammoth Spring (measured flows ranged from 240 to 431 ft^3/s) on the Spring River, and Big Spring (average flow of 428 ft^3/s; Vineyard and Feder, 1974) on the Current River. In 1974, 134 mi of the Current River and its principal tributary, Jacks Fork, and about 65,000 acres of adjoining land were designated as the Ozark National Scenic Riverways (Barks, 1978) to preserve the natural conditions of the Current River Basin and to increase recreational opportunities for fishermen, canoeists, and campers. A part of the Eleven Point River in Missouri also has been designated as a National Scenic River.

Stream Morphology

Some of the major rivers and their tributaries lie totally within a single physiographic section; however, more typically, a large stream will flow through two or more physiographic sections and, as it does, the stream morphology changes. Descriptions of typical stream morphology for each of the physiographic sections or areas follow.

The terrain in the Boston Mountains is exceptionally steep and rugged with local relief as much as 1,000 ft in places (Bennett and others, 1987). Because of the rugged terrain and steep slopes, streams have high gradients, averaging about 20 ft/mi (Giese and others, 1987). Stream beds consist predominantly of bedrock and rubble with smaller amounts of boulders, gravel, and sand.

Relief in the Springfield and Salem Plateaus generally is less than that in the Boston Mountains. Valleys generally are deeper and narrower and the ridges sharper in the Salem Plateau than in the Springfield Plateau. Local relief along the major streams often exceeds 300 ft (Pflieger, 1989) and is as much as 500 ft in some areas. Stream channels in the Springfield and Salem Plateaus consist of a series of well-defined riffles and pools, and channel beds consist predominantly of coarse gravel, rubble, boulders, and bedrock. Stream gradients generally exceed 3 ft/mi even in the larger streams and are as much as 50 ft/mi in some headwater areas (Pflieger, 1989). The water usually is quite clear. In some areas of the Springfield and Salem Plateaus, forests have been cleared to develop land for agricultural purposes resulting in a reduction in the tree canopy overhanging streams. This reduction allows more sunlight to reach the stream, which can increase water temperatures and the growth of aquatic vegetation.

Streams in the St. Francois Mountains within the Salem Plateau have high stream gradients. Pflieger (1989) does not differentiate between the morphology

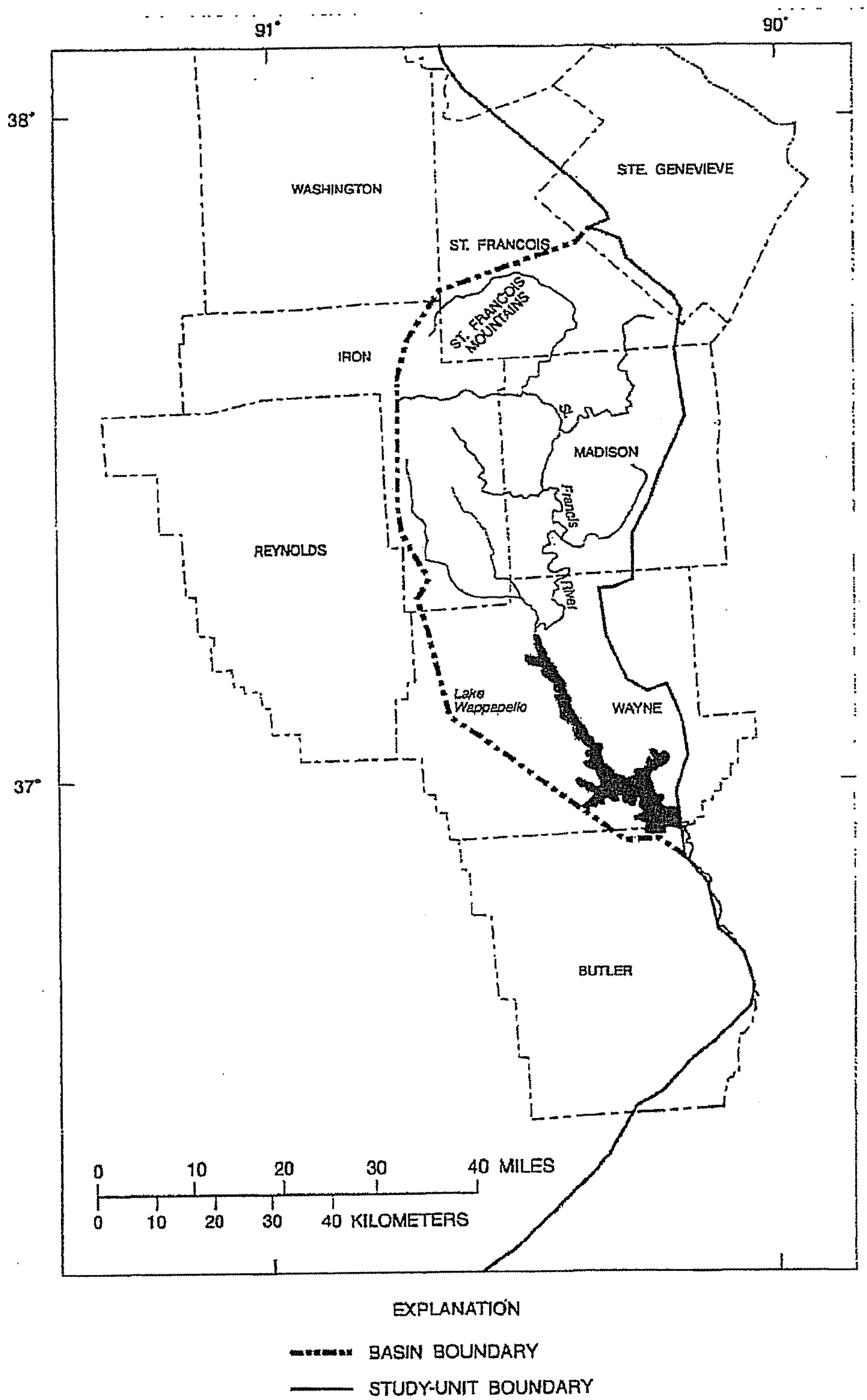


Figure 21. St. Francis River Basin with major tributaries and reservoir.

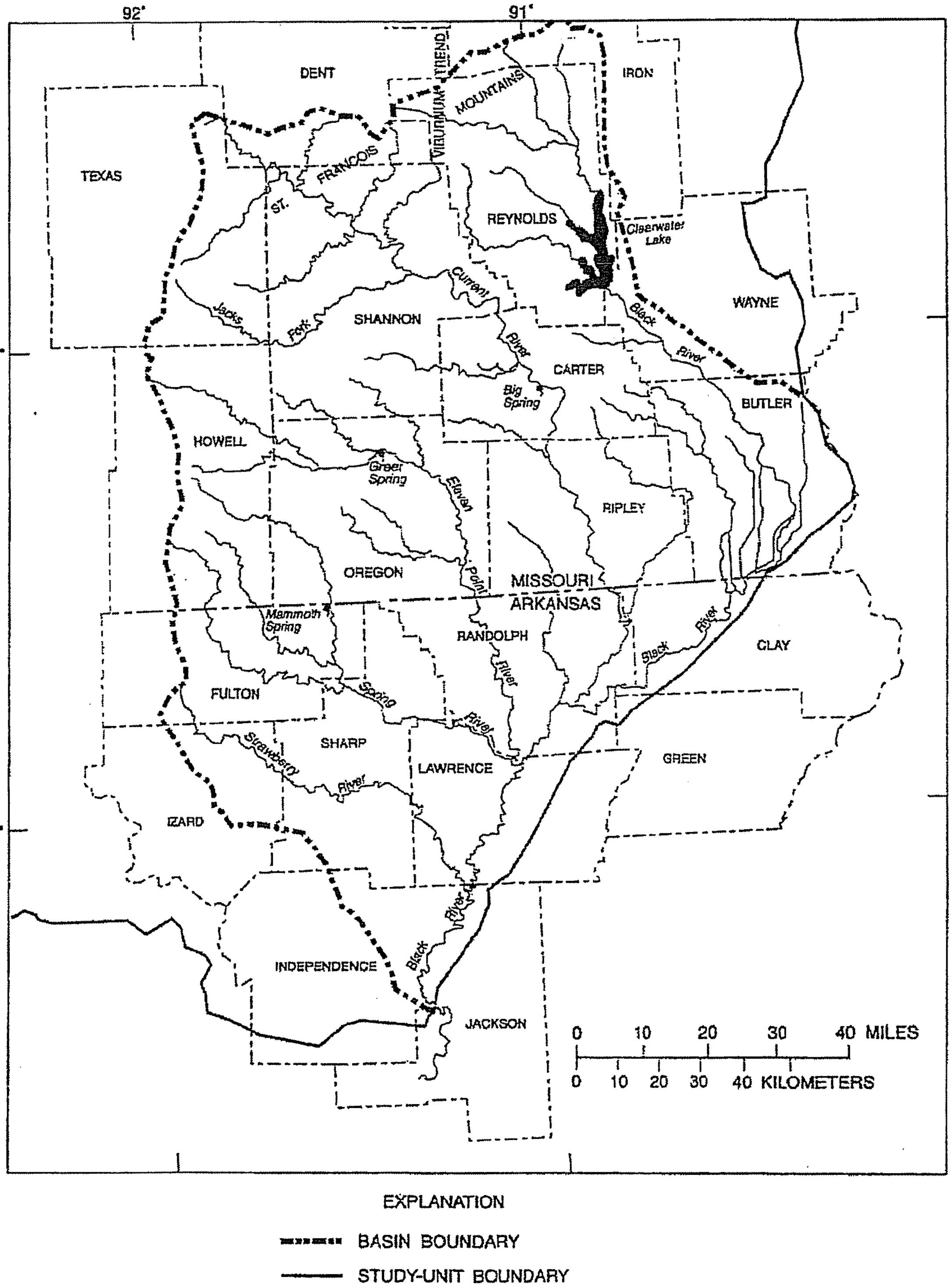


Figure 22. Black River Basin with major tributaries, reservoir, and springs.

of the St. Francois Mountains and the rest of the Salem Plateau. Therefore, the morphology of streams in the St. Francois Mountains probably is similar to that of streams in other parts of the Salem Plateau; however, stream gradients are as much as 200 ft/mi in some headwater stream reaches. A distinctive valley form, called a shut-in, is formed where streams erode resistant igneous rocks in the St. Francois Mountains. The results are steeply sided valleys and cascading waterfalls (Beveridge and Vineyard, 1990).

Streams in the Osage Plains occupy broad, shallow valleys and, if unchannelized, follow meandering courses. Gradients average about 26 ft/mi in headwater areas but average less than 2 ft/mi in the larger streams (Pflieger, 1989). Channels consist of long pools, and riffles are often nonexistent or poorly defined. Sand and silt channel beds are dominant in the pools; shale and sandstone gravel and pebbles are dominant in the riffles.

Streams in the Mississippi Alluvial Plain meander through a broad alluvial plain. Oxbow lakes are common along the lower reach of the Black and Current Rivers. Many of the streams have been channelized. Maximum relief is only a few feet per mile (Bennett and others, 1987). Stream gradients generally are less than 1 ft/mi. The channel bed in swifter areas of streams and ditches is mostly sand and gravel; in areas of less velocity, the channel bed is usually silt (Pflieger, 1989).

Runoff and Streamflow

Runoff can be defined as the water that drains from the land into stream or river channels after precipitation and is a function of precipitation amounts, topography, geology, soil moisture, and other factors. Mean annual runoff per square mile of basin, which can be computed by dividing the mean annual volume of water leaving the basin (measured as streamflow at a gaging station) by the area of that basin, is often used for purposes of comparing runoff characteristics between basins.

Mean annual runoff within the Ozark Plateaus study unit is shown in figure 23 (Gebert and others, 1987). Mean annual runoff generally is least in the Osage Plains where it ranges from about 9 to 10 in. Mean annual runoff in the Springfield and Salem Plateaus, and St. Francois Mountains generally ranges from 10 to 15 in., although values are more variable in the eastern Salem Plateau where they range from about 4 to 30 in. (Hedman and others, 1987). Mean annual runoff is about 16 in. in the Mississippi Alluvial Plain within the study unit (Neely, 1986). The mean annual runoff generally is greatest in the Boston Mountains where it ranges from 14 to 20 in.

Magnitude, frequency, and duration of floods and high streamflows are affected by many factors, including drainage area, basin and channel slope, channel length, precipitation amount and intensity, vegetation, season, and flow-regulation activities or structures. Flood-frequency and flood-magnitude information for streams in the study unit are available in reports for Arkansas (Neely, 1987), Kansas (Jordan and Irza, 1975), Missouri (Sandhaus and Skelton, 1968; Hauth, 1974), and Oklahoma (Sauer, 1974; Thomas and Corley, 1977).

Duration of high streamflows (and the time lag between onset of precipitation and the peak flow) generally will be shortest in small, steep basins. The location of streamflow stations and hydrographs that exemplify this type of response for the Neosho River and Lightning Creek in the Osage Plains, and the Current River and Jacks Fork in the Salem Plateau are shown in figures 24 and 25. Streamflow is elevated for longer periods of time in the Osage Plains streams and in the streams with larger drainage areas. Although these examples are typical, the duration and magnitude of streamflow peaks at a specific location are strongly dependent on antecedent precipitation and precipitation intensity, duration, and distribution.

Annual mean streamflow of individual streams within the Ozark Plateaus study unit can vary substantially from year to year (fig. 26). Between 1951 and 1990, there were periods of low flows in the mid-1950's, mid-1960's, and early 1980's, and periods of generally high flows in the early 1950's, early and late 1960's, mid-1970's, and mid-1980's. Annual mean streamflows for water year 1981 were extremely low throughout the study unit but annual mean streamflows just 4 years later, in 1985, were among the highest for the period of record. Although, these patterns generally are regionally consistent, local climatological differences also affect annual mean streamflows.

Runoff and streamflow also vary seasonally. Minimum monthly streamflows typically occur in summer and fall, July through October (fig 27). Maximum monthly streamflows typically occur in spring, March through May (fig. 27). These seasonal variations in streamflow primarily are the result of seasonal differ-